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CLV.

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THE IMPROVEMENT OF THE SOUTH BOSTON FLATS

BY THE HARBOR COMMISSIONERS OF THE STATE OF MASSACHUSETTS.

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Presented February 20th, 1878.

It was found, some twenty years since that the upper harbor of Boston, between the end of Long Wharf and the Castle Island narrows, had become so much shoaler during the past century, that considerable inconvenience had been occasioned to the commerce of the port.

Seeking relief from this steadily increasing evil, the city government in 1860, by Hon. F. W. Lincoln, Mayor, called in the aid of a commission of experts whom the President appointed for the purpose, consisting of the Chief Engineer of the United States Army, Gen. Jos. G. Totten, the Superintendent of the United States National Observatory, Admiral Chas. H. Davis, and the Superintendent of the Coast Survey, Prof. A. D. Bache. These commissioners undertook by careful hydrographic surveys and researches based thereon to account for the changes that had taken place, and to recommend such action as might be advisable to remedy the evils. They embodied their researches and advice in ten reports to the city government, of which a short abstract is given below; but owing to the magnitude of the works recommended it was considered to be more appropriate for the State and Federal Governments than for the city alone to carry them out.

In pursuance of this view, the Federal Government has accomplished important work in the lower harbor along the line of the main ship channel. The State Legislature also passed an act in 1866, constituting a Board of Harbor Commissioners to whom was committed the interests of the State in guarding against all encroachments and deterioration from

whatever causes in all the harbors of the State, and with particular reference to remedying the shoaling of the upper harbor of Boston by the works recommended. The former Board of Federal officers was retained as an "Advisory Board" to co-operate and advise in these important improvements. On the death of Gen. Totten, his place was filled by his successor, Gen. Delafield, Chief Engineer of the United States Army, and on the death of Prof. Bache, his place was filled by Prof. Benj. Pierce, Superintendent of the Coast Survey. Prof. Henry Mitchell, assistant in the Coast Survey, was added to their number.

It was found by these commissioners that like many growing cities situated on navigable waters with shoal margins, Boston had been gradually built out into the tide water, by the reclamation of these margins for wharves, streets and buildings, so that the densely peopled portion of the city occupies now an area about half of which was once covered by the daily tides. This change had produced a marked effect upon the tidal currents of the upper harbor. It changed the line of the shore so as to alter the direction of the currents in some places, leaving former channels to be slowly filled by deposit of suspended matter, while the loss of the tidal prism, displaced by the filling of reclaimed margins had seriously diminished the volume and scouring force of the flow in the immediate vicinity of and below the city.

If we draw a line across from Deer Island to Point Allerton, connecting the headlands at the mouth of the harbor (see Chart, Plate VIII), we shall enclose an area subject to tidal flowage of about forty-five square miles, with an average tide of ten feet. Thus an enormous mass of water passes these headlands in its flux and reflux every six hours. The loss of the tidal prism on the surface formerly flowed and now reclaimed does not sensibly affect the volume of water daily passing this strait, which is some three miles wide, but that loss *does* materially affect the volume flowing through the part of the harbor above Castle Island, where the deterioration had taken place. The volume of fresh water flowing into the harbor is never large, and the depth of its channels is only to be maintained by the tidal scour. The tidal action, however, serves to intensify the power of the land water by damming it back one-half the time, to be delivered during the ebb with double its average volume. Tidal currents also give a definite resultant in one direction, not canceled by the return flow, owing to the configuration of the shores, which often throw the flood and ebb currents in different paths. Even when following the same path, which is sometimes the case, the ebb is generally

more efficient in scouring, not only from its being reinforced by the land water, but because its course is *concentrative*, accumulating velocity as it goes, while that of the flood is *dispersive*, losing velocity as it scatters laterally, over the flats on either side the channels.

There is one point, however, in Boston harbor where the flood was found to be a stronger current than the ebb, viz., above the Castle Island narrows. But before arriving at a point opposite East Boston, the flood current loses force by lateral dispersion, and the ebb is as usual the stronger. Thus the flood current being checked here, tended to deposit suspended matter.

The ebb tide also, in issuing from the strait between Boston and East Boston is suddenly checked by several local causes, all combining to produce loss of velocity and consequent deposits. Among these causes are the following: (*a.*) The large lateral expansion of the ebb, and consequent dispersion over the area between South Boston and East Boston. (*b.*) The want of accord between the ebb tides of the basins of Charles and Mystic rivers. The latter discharges most of its tidal prism from a near point, and having but little area to deliver water from after half ebb, owing to its extensive flats left bare at that time, gives most of its water to the harbor early in the ebb flow, and has but little left for the latter half of the ebb. The basin of Charles river however is further up stream than that of the Mystic, while the numerous pile bridges which cross between Boston and its northern suburbs oppose by over eleven thousand piles the flow of the current to a marked extent. The result is, that the ebb from the Charles runs with most force after that from the Mystic is mostly expended, and continues to run with force through these bridges for some time after the flood current has entered the upper harbor. Thus these two important basins lose much of their efficiency for tidal scour by lack of unity in their action. (*c.*) Another, though a minor agent, in checking the ebb at this point is found in the direction of the ebb from the south bay which debouches into the upper harbor by Fort Point channel in a direction almost diametrically opposed to that of the ebb from the northern basins, serving thereby not only to cancel its own momentum but to check as far as it may that of the other currents.

Reasoning from the above state of things which was deduced from their surveys, the Board of Special Commissioners recommended at an early day the enclosure of the South Boston flats by a wall extending along the southerly side of the main ship channel towards Castle Island,

and connecting with the east side of Fort Point channel by an easy curve, while the western side of this channel near its junction with the harbor was to be built out in a parallel curve, as shown on Plate IX. By this means the ebb current from the south bay would be prevented from wasting its force and that of the northern channels, and would be led by the curved bank on its west side to follow the line of its eastern side, along the new wall, till its direction should essentially contribute to, rather than check, the velocity and momentum of the ebb in the ship channel. Moreover, the walling in and reclamation of this extensive area of flats on the South Boston side would so far prevent the former dispersion of the ebb, as to add vastly to its scouring power in the ship channel. The construction of a similar wall along the north side of the ship channel from East Boston towards Governor's Island was also discussed, passing along where Bird Island had formerly existed, and thus serving to prevent the undue dispersion of the ebb tide on this side. The efficiency of such a remedial measure was not doubted, but there was too little prospect of recouping the cost of such a work, by the value of the lands reclaimed for commercial uses, to justify such an undertaking. The prospect of a demand for such lands on the South Boston side was, however, considered sufficient to warrant the enterprise, and in 1868 a tract of some twenty-five acres on the east side of Fort Point channel was sold to the Boston Wharf Company to be walled in and filled. The Harbor Commissioners being authorized also, made contracts in 1868 on behalf of the State for walling in and filling the portion of these flats north of those sold to the Boston Wharf Company, nearest to and along Fort Point channel, for a compensation in a part of reclaimed lands; but as the terms of the contract did not meet the approval of the Executive, the subject was dropped. In the year 1873, an appropriation of money having been made for the purpose by the Legislature, the Harbor Commissioners made contracts for the building of about 720 feet of light wall on piles along the east side of Fort Point channel from the lands filled by the Boston Wharf Company, northward—and thence for the building of a heavy sea wall around the curve as shown on Plate IX, to the boundary line of flats sold to the Boston and Albany Railroad Company, with the filling in of about twenty-five acres of land enclosed.

This last-named corporation, having purchased a tract of about 50 acres on the easterly side of the above, agreed to wall in the same along the front or harbor line and fill in behind the wall the whole of said 50 acres, reserving such portions as might be needed for docks or tidal

basins for the use of vessels. The filling and walliug was to progress in connection with the improvement of the 25 acre tract improved by the State, and contracts were made by the railroad company with the same parties who contracted for the work done by the Harbor Commissioners at similar prices and subject to similar plans and specifications. The work then contracted for has made some progress and the work of improving the State's tract of 25 acres has been finished. That undertaken by the railroad company is still in progress. The material for filling up to grade 13 above mean low water was to be of clay taken from the harbor between the walls and the main ship channel, by dredging to a level of 23 feet below mean low water. Three feet of clean gravel ballast was to be, and has been placed on this clay, raising the improved tracts to a level of 16 feet above mean low water, or 2 feet above high water of extreme spring tides.

The following specifications describe the work done by the State :

LIGHT SEA-WALL.

SECTION 1. Said wall shall be built in such location as shall be marked out by the Engineer of the Board of Harbor Commissioners, previous to the commencement of operations by the contractor; and the contractor shall preserve the location of said line by driving piles to mark the location of the wall permanently.

The trench shall be dredged for the wall, under the direction of said Engineer, to a depth of two feet below low water spring tides.

The foundation piles to support the wall shall occupy a space nine feet wide, having five piles in parallel rows, said rows to be two and one-half feet distant from centre to centre of each row.

All piles shall be driven into the hard clay stratum to the satisfaction of the Engineer of the Harbor Commissioners. The piles to be in diameter not less than ten inches at low-water mark spring tides, at which point they are to be sawed off level with each other.

On the top of the piles are to be spiked two layers of spruce plank twelve inches wide and three inches thick, lying at right angles with each other. The space between the heads of the piles for two feet in depth to be filled and well rammed with stone chip ballast or oyster shells.

The wall from low water of spring tides to the top of the coping stones or grade sixteen, shall be eighteen feet in height, with a true batter front and rear. The wall shall be nine feet wide at the bottom, five feet wide at the top, including an offset of one foot for a resting

place for cap to support the ends of platform joists; to be constructed of good quality granite rubble wall stones, from eighteen inches to two feet thick, with sufficient headers to secure the stability of the wall, well bonded and pinned throughout.

The rear of the wall shall be ballasted with oyster shells, from the back of the wall to a line commencing at a point two feet in rear of the back of the top of the wall, and extending in a slope of forty-five degrees to the base of the wall, as shown on annexed plan marked X.

At the end of the wall a flank wall shall be built to connect this wall with the adjoining heavy sea-wall, according to the direction of the Engineer of the Board of Harbor Commissioners.

This wall to be commenced within thirty days after notice that the location of the wall is made, and the work to be prosecuted without delay to its completion, and completed on or before the first day of May, eighteen hundred and seventy-four.

Heavy Sea-Wall.

Sec. 2. The base of this sea-wall shall be built on a line parallel to said modified line, and one foot within the same as aforesaid and in such location as shall be marked out by the Engineer of the Board of Harbor Commissioners, previous to the commencement of operations by the contractor; and the contractor shall preserve the location of said line by driving piles to mark the location of the wall permanently. This sea-wall shall be built in accordance with the plan marked XI, hereto annexed.

The trench for this sea-wall shall be excavated to the satisfaction of said Engineer, forty-five feet in width at the bottom, which shall be as nearly as practicable a level surface. The depth of the trench shall be at least twenty-three feet below mean low water and always to hard bottom.

This trench is to be filled with broken quarry stones of mixed sizes, none less than seventy-five pounds weight, thrown in and deposited in regular layers of not over four feet each in depth, and each layer is to be placed compactly by divers with bars before depositing the next layer.

This filling is to be forty-five feet in width at the bottom and for the lower three feet of its depth, thence sloping inward on each side with a slope of one and a half horizontal to one vertical for a further depth of nine feet, where, at a level of eleven feet below mean low water it is to

be eighteen feet in width. The filling is to be levelled up here with smaller chips of quarry stone to receive the wall, and the outer or harbor slope is to have the interstices well filled with similar chips.

The wall to the height of one foot below low water shall be built in quarry face dimension stone of granite, laid in courses of two feet rise each, by the aid of submarine divers. The courses shall be laid alternately, entirely with headers and stretchers, the bottom or first course being headers. Each stone shall be at least four feet, and not more than ten feet long, at least eighteen inches wide, and exactly two feet rise, fitted to one inch joints, square ends and out of wind.

The wall shall be compactly laid in a substantial and workmanlike manner, with fair and close outer face. Stones shall be laid so as to break joints everywhere, with good and sufficient bearing upon the beds without pinners.

The base of the wall shall be fourteen feet. The height of the wall to one foot below mean low water, ten feet, and the thickness of the wall at top, eleven feet four inches.

The wall from one foot below mean low water to the top of the coping stones, or grade sixteen, shall be laid with dimension stone, in cement. The courses shall be laid with headers and stretchers, with not over ten feet interval between the headers, and have two feet rise, with the exception of the coping course, which shall have a rise of three feet, and be entirely of headers. The stretchers shall be at least four feet long, and the headers shall not be less than six feet long from face inwardly. The batter of each face shall be two inches to the foot.

The base of this wall shall be nine feet eight inches; the height, seventeen feet; and the thickness at the top of the wall, five feet.

The back of the whole of the heavy wall from top to bottom shall be ballasted with clean gravel, cobbles or oyster shells, resting at a slope as steep as they will stand, or forty-five degrees, and tapering to nothing at the top of the wall.

This wall shall be commenced by the first day of May, 1874, and finished by the first day of August, 1875.

Sec. 3. Spaces in said walls for docks, or purpose of filling by scows, or any other purpose, may at any time be reserved, permanently or temporarily, by said Board of Harbor Commissioners, upon notice before the structure of the wall is begun in any such space, and where such space is permanently reserved, it shall be filled by a strong bulk-head, to the satisfaction of the said Engineer.

Filling.

Sec. 4. The parcel of flats to be filled is situated at the easterly junction of the main and Fort Point channels in Boston harbor, bounded southwest by the flats of the Boston Wharf Company, and southeast by flats sold to the Boston & Albany Railroad Company, and containing about a million square feet, more or less.

The filling must be up to grade sixteen. Up to grade thirteen the filling must be with materials dredged from the mouth of Fort Point channel below the line of Oliver street extended, and from that part of Boston Harbor represented by the space colored red on the "Plan for the occupation of flats owned by the Commonwealth in Boston Harbor," appended to the sixth annual report of the Board of Harbor Commissioners, and other portions of Boston Harbor above a line extended from Buoy No. 11, at right angles with the line of said sea-wall, on the main channel. Such portions of Boston Harbor are to be dredged to a uniform depth of twenty-three feet at mean low water. Such portion of Fort Point channel is to be so dredged that the bottom shall uniformly and gradually slope from a depth of twelve feet at mean low water at the line of Oliver street to a depth of twenty-three feet at the southwest border of the area represented by the space colored red on said plan. The residue of the filling to grade sixteen must be with good clean gravel. The whole filling to be finished on or before October 1st, 1876. Where the said sea-walls to be built around said flats shall not be built so as to furnish the requisite protection to the filling, temporary bulkheads must be built for that purpose, as required by the Board of Harbor Commissioners. Spaces required for docks may be reserved at any time from filling by the Board of Harbor Commissioners.

Location and Construction of Dock.

It was concluded during the progress of the work to construct a dock or tidal basin on the portion put under contract, the location and size of which is shewn on Plate IX. This plate shows by a heavy black line the location of the walls constructed up to this date along Fort Point Channel and around to the second dock.

The wall around the docks is classed as "Light Wall," being of the same construction as that on the east side of Fort Point channel. It is founded on five rows of piles driven from 20 to 30 feet into the bottom, about 10 feet of which is a stiff clay, affording a satisfactory foundation

for vertical loads, but the superficial part of the deposit was generally quite soft, affording but little lateral support. A section of this wall is shown on Plate X. The timber platform shown on this section has not yet been constructed. This structure is intended to provide width for the slope of the clay between the deep water of the berths in its front and the top of the piling under the wall, which is only two feet below low water. If the piles were exposed to the water, they would speedily be destroyed by worms.

Since this slope near the mouth of the docks is more exposed to the erosion of waves and currents than elsewhere on the light walls, the clay could not be depended upon here to stand at so steep a slope as elsewhere, so a greater width is here required for the platform. A width of 20 feet from the bottom of the wall is provided in the interior part of the dock, and as it is desirable to keep the front line of the platform straight, or, at any rate, not to allow it to encroach upon the width of the dock, the walls are deflected back near its mouth, so as to allow a width of 40 feet at the outer ends. If the platform had been here limited to a width of 20 feet, and the dock walls built straight, it would have been necessary to start the foundation of these walls several feet deeper; and as the stone could not have been so laid without submarine divers, such a plan would have largely increased the cost, without adding to the stability of the permanent work. The greater width of the platform is an increase of the amount of work subject to renewals, but does not affect the permanent portions of the works, except as here stated. The walls around this dock were constructed in 1876, the foundations having been largely prepared during the previous winter.

In Table A will be found a record of the actual settlement of these light walls, averaging about 2 inches up to this date, being chiefly due to the indentation of the bottom stone into the plank, and the springing of the plank to get a complete bearing on each pile head.

Owing to the rapid filling of certain portions of the space during the last season, slight forward movements took place, as follows: At a point about 200 feet from the southwest corner of the dock it moved forward 6 inches. At a point on the east side of the dock, about 25 feet from its junction with the heavy wall, it moved forward 6 inches. This motion did not appear to continue in any case beyond the period during which the semi-fluid clay filling was expelling the water with which it had been mixed by handling, and which floated out of it shortly after being dumped.

The Fort Point channel wall was continued with the same light section till it reached a depth of some 19 feet of water at low water in the channel which was dredged along its front, with an increasing depth as it approached the open harbor. No greater depth than this could be safely maintained along the front of a wall of this light class, unless greater width were given for the timber platform, to provide for the slope of the bottom upward from the channel towards the wall, to cover the piles. For this reason, and for others connected with the tidal currents, the point indicated by the offset on the plan (Plate IX) was selected for beginning the heavy wall. The light wall was set back 25 feet at the bottom from the harbor line, to give room for the platform and the slope under it, but the heavy wall, being founded 23 feet below low water, is built on the harbor line.

This light wall on Fort Point channel was begun in March, 1874, the foundations having been partly prepared during the previous winter. It was completed in the autumn of the same year, except for a short distance where it connects with the heavy wall beyond by a spur running out to the harbor line.

The settlement of this light wall is recorded in Table A. Early after its completion this wall was filled up to grade 13 with clay, and a large pile was left temporarily at a higher level near the beginning of the curve. Directly afterwards a forward movement of the wall was observed, about a foot in amount, and tapering out in about 200 feet of length each way. The pile of clay was soon removed by spreading on to adjacent spaces, and no further movement has been detected here since. The coping had been considerably disturbed by the hoisting of clay over it, and was reset in 1877, on a straight line, leaving the offset below the coping of slightly irregular width.

A tabular statement of the results of the pile driving for this wall and the dock wall is appended, which may serve as a criterion from which to judge of the character of the material, and to compare with similar material in other works to be constructed. See Tables *J* and *K*.

The Heavy Sea Wall west of the Docks.

From the end of this light wall, for a distance of 803 feet along the coping, around the curve to the first dock, we have a heavy sea wall, a section of which is shown on Plate XI.

The plan originally proposed for this wall is shown on Plate XII, except that no ballast was then provided behind or under it. It was

approved in 1868 by Major-General J. G. Foster, George R. Baldwin, James B. Francis, and T. Willis Pratt, four engineers of high standing. It was the plan contemplated in the contracts above alluded to as having been made at that time, which were not approved by the Executive.

Upon subsequently examining the character of the foundation on which this wall west of the dock was to rest, it was found that some parts of the clay bed were much softer than others, to such a degree that it was feared an unequal settlement might occur if this plan were to be carried out, so as perhaps to endanger its stability. Moreover, the slippery nature of the clay bottom might lead to its being pushed bodily forward when loaded by the filling behind it. It was found that a wall built on a foundation of broken stone, as shown on Plate XI would cost rather less than if built entirely of dimension-stone, while the inspection necessary to secure good work would also be less difficult. Moreover, though the weight of this broken stone would force the lower portions into the clay unequally, because of its unequal softness, thereby causing an unequal settlement when first applied, this unequal settlement would, it was thought, reach its limits before imposing the weight of the dimension-stone, so it could be levelled up after such settlement. After consultation with Mr. James B. Francis, C. E., this plan with the broken stone base was therefore adopted for the portion of the wall under consideration.

As the foundation of this wall is at the same level with the harbor floor in its front, it might be exposed to undermining if any scour were to occur along its base. But repeated observations have shown that there is a slight but constant accretion of mud here, so that we only had to be careful to get every part of the foundation down to the proposed grade.

This work was begun by depositing the broken stone after dredging the trench, in April, 1874, and nearly the whole mass, or about 12,000 cubic yards, was deposited during that season, and partly levelled up after waiting for its settlement. Large stones were deposited at first, and their interstices filled by smaller ones placed roughly by divers as specified. It was found that some inconvenience arose in complying with the smaller limit of 75 lbs. weight named in the specifications, and this point was waived, stones being received of any size, provided they were of such a mixture of sizes as to secure compactness.

This work received the repeated inspection of divers employed by the State, as well as the occasional personal inspection of the assistant

engineer in charge, Mr. Joseph O, Osgood, whose reports were far more reliable and intelligent than those of ordinary divers. The success of the structure is largely due to these precautions, without which such a foundation would be likely to give much trouble by subsequent unequal settling.

Previous to beginning the work of laying the dimension-stone, this foundation was carefully levelled up to the proper grade, as follows: Before depositing the broken stones, guide piles had been driven in the line of the upper angles of the slopes of the foundation, both outside and inside the future wall. These were driven in pairs, about 30 feet apart between pairs, the inner one of each pair being located by triangulation and the outer one measured out from it. A line of planks, running lengthwise the wall, was spiked to each row, so the upper edge of the plank should be at the level of 11 feet below low water, the grade for levelling this material. Iron straight-edges, some 20 feet long, were then laid across from plank to plank, and the stone chips applied to bring the material up to the plane thus indicated. The front row of plank was also used to support a straight-edge resting on the front slope, with a triangle on it of the proper angle, carrying a level on its upper edge, for dressing this slope to the prescribed plane. It was of course important to fill all hollows in this slope which might lead to the slipping out of the material from under the wall, and all angular stones projecting beyond the plane so as to threaten injury to vessels, were either taken out or filled around with small stones.

Alignment of the Heavy Walls.

Since these walls were located about a quarter of a mile from *terra firma*, and were to occupy a definite line prescribed by the Harbor Commissioners on curves of 908½ and 2368½ feet radius, considerable pains were required to set out and maintain these lines during the construc tion. The surface, when the work began, was nearly bare at low water, but covered some twelve feet at high water, and was to be dredged some 20 feet deeper. The following method was adopted. Clusters of piles, four or more in a place, were driven about one hundred feet apart, and fifty feet back from the line of the wall, so as to be out of the way of the foundation trench. The piles in each cluster were drawn together by bolts at the top. One of these clusters, or dolphins, was located at the beginning of the curve of 908½ feet radius and one at its centre, built larger and firmer than the others, and carrying on its top a small plat-

form on which a transit could be placed. The transit at the centre of the curve measured off the angles between radial lines marked on those dolphins around the circumference, and another transit on the dolphin at the beginning of the curve, starting from a tangent laid off in succession half the corresponding central angles intersecting the radial lines previously established; these intersections thus became successive points in a circle fifty feet inside the line of the wall and concentric with it. Whenever a line was needed on the wall, the measurement of fifty feet in range with the centre, from the points established on any two of the dolphins, would readily give it, the lengths of the chords between the dolphins always defining the length of the corresponding chords on the wall line. These dolphins were frequently knocked about by tug-boats and scows, and during the first winter were badly treated by the ice, requiring frequent renewals of the points on them, as well as renewals and repairs of the dolphins themselves.

The line for the dimension stones was given as follows: Points were made upon temporary skeleton stages, spiked to the guide piles opposite each dolphin by measuring out from the same. A heavy plummet was swung from these points on to the foundation below, where a diver stood ready to place a heavy stone and drill a hole in it for a bolt under the plummet. A line was then drawn on the chord between any two of these bolts, and the appropriate ordinates set off for intermediate points by the diver, according to a list furnished him, whenever he wished to align the face stones.

The successive courses were laid by making offsets from the one last laid, verified occasionally by reference to the dolphins.

During the month of August, 1874, the work of laying the dimension stone began, and progressed, whenever the weather allowed, during the autumn, though only some 1,100 cubic yards were laid before the inclemency of the weather caused a suspension for the winter.

In the beginning of this work it was attempted to use stone of tapering widths in the stretcher courses, which was not objected to if other stone were selected or shaped to conform roughly to their shape when laid alongside of them. But as the water was rarely clear enough for any length of time to allow the divers to see objects over two feet from their eyes, this adaptation of one stone in hand to another already laid was found to be impracticable, without greater cost than to prepare them with parallel sides. This method was, therefore, pursued by the contractor after awhile, except for the courses consisting entirely of headers,

which were got out in pairs or single stones, and could more readily be laid heads to points than the courses consisting entirely of stretchers. In order to ensure proper bearings, it was found necessary to gauge the thickness of every stone before lowering it into the water.

The attainment of "one inch joints," and "good bearings without pinners," required by the specification, occasioned much trouble and constant vigilance on the part of the inspector, as well as greater cost in fitting on the part of the contractors than they had anticipated. It occurred here, as in other places where stone are laid in uniform courses, that bunches were often found on the top of a course already laid, arising from slight excess of thickness or a slightly winding surface. Such bunches are readily detected, and readily pointed down after laying, when laying stone above water, but not so in submarine work. If allowed to remain, the next stone above, which may be ten feet long, is tilted up an inch at the end by a bunch of half an inch under its middle, and the error goes on increasing as we go up, for the difficulty of finding such places in muddy water prevents selecting thinner stone to lie over them. The inevitable result would be the breaking of all long stones. Even when the bearings are good for the whole length of a stone, the slack places in its bed, coming over similar slack places of half an inch depth in the build of the lower stone, will make plenty of joints a full inch open, so it becomes very necessary to look out for the winding stones and those having bunches, however small beyond the planes of bearing, *before* they are lowered into the water, for it is too costly to bring them up for refitting.

The completion of this work occupied the whole of the years 1875 and 1876. It is now a year since it was loaded by the filling, and its stability has been quite satisfactory. The actual settlement of its lower course along its whole length, and its progress in detail, is given in the tables B and C, together with the present level of the top of coping above mean low water. The settling of the granite wall has taken place with such uniformity that scarce any cracks have been formed in the cemented joints of the coping. The largest crack had opened about one-fourth of an inch over a year ago at the top. It was repointed in 1876, and subsequently opened one-eighth of an inch. It has been again pointed in 1877, and now shows nearly one-sixteenth of an inch opening. The total motion is therefore less than half an inch, and appears to be decreasing. No forward or lateral movement has been detected in this wall, except the very slight one indicated by this crack. Not a stone has been broken by this movement.

This wall, as now built, is certainly capable of resisting a much greater thrust, without sliding forward on its bed, than if the dimension-stone had been laid directly on the clay, for its base is composed of large angular stones, imbedded in the clay by the superincumbent load, while it covers by its base more than double the width of a wall built as at first proposed, entirely of block-stone from the bottom. In constructing it, the broken stone, as above described, were mostly deposited in 1874, and were allowed to remain till the following year before proceeding with the dimension-stone above. In fact, only 1,200 cubic yards of the latter were laid prior to April, 1875. The unequal settlement of the broken stone actually taking place on the different qualities of material, really caused no practical inconvenience, for this work was levelled up after such unequal settlement had nearly reached its limits.

Heavy Wall East of the Dock.

In providing for the strip of heavy wall along the harbor-line east of the dock on the flats belonging to the State, and between this and the dock on the flats of the Boston & Albany Railroad Company, the same reasons did not appear to exist for the base of broken stone twelve feet high which had existed on the portion described above, west of the dock. Between the two docks the foundation was quite uniform in texture, giving less reason than further west for unequal settlement, while the conditions of the back filling were such as to impose a lighter load per linear foot of the whole work, for this filling was only to extend against the central portion of its length, 156 feet only being filled out of a total length of about 180 feet, the dock walls being connected with it about 32 feet back from its ends. Still another reason appeared for adhering to the principal features of the original plan at this place, viz., the greater exposure here existing to the erosive effect of waves on the bottom, which might perhaps disturb a foundation of broken stones having a steep slope. It was therefore determined to adhere to a modification of the original plan for this part of the heavy wall which was built as indicated on Plan XII, the modification referred to being this. The foundation was dredged about four feet below the base of the wall, and the trench filled with small broken stones to diminish the risk of slipping. Previous, however, to advising this style of wall at this place, the bottom was thoroughly tested. A description of these experiments may be of interest.*

* The writer is indebted to Mr. Jos. P. Frizzell for conducting these experiments, with Mr. J. O. Osgood, inspector.

The dredging having been completed along the whole length of the proposed pier-head to the required depth of 23 feet below low water, piles were driven at intervals, in order to learn what degree of uniformity existed in the general character of the bottom. The dredging and pile-driving both tended to show a great uniformity in the physical characteristics of the bottom along the whole length of the work. It was a firm though fine clay, soft enough to allow of piles being driven into it with ease. Selecting a central point for the experiment, a group of piles was driven into it and fastened together at the top, where a small platform was built on them. A single pile, with squarely-sawed point, was set upright, resting its point on the clay, while its top was held vertically over its lower end by the platform, through a hole in which it was allowed to slide. A small cross-head was then made fast to the top of this loose pile, on which definite weights were applied, while the amount of settlement under these weights was observed by a levelling instrument, and referred to a fixed bench-mark.

The results were as follows :

The figures under the head of "settlement" indicate the new or additional subsidence due to the increase of load.

Total weight in pounds applied.	Pounds per square foot of bearing surface.	Settlement in feet.	Interval during which settlement occurred before it was measured.
670	2,921	0.03	17 hours.
1,300	5,668	0.06	7½ hours.
2,500	10,900	0.04	At once.
2,500	10,900	0.05*	16 hours.
2,830	16,700	0.04	At once.
2,830	16,700	0.20*	7 hours.
2,830	16,700	0.25*	21 hours more.
2,830	16,700	0.00*	72 hours more.
2,830	16,700	0.03*	72 hours more.
2,830	16,700	0.025*	¼ hour more.

This material can be compared to that existing in other places by comparing the amount of resistance offered by each material to the penetration of square-pointed piles under the hammer; and for the sake of such a comparison, a statement is given below of the successive penetration of several piles here driven. The hammer weighed 1,385 pounds. The piles were selected of about the same size, viz., 6½ inches diameter at the point; they varied from 43 to 53 feet in length. The water was about deep enough to float the piles as they stood upright before being driven, so their own weight counted for nothing.

* Additional.

		Blow.	Fall of hammer.	Penetration.
Platform piles.	First pile	1st.	8 ft.	7½ inches.
	"	2d.	8 ft. 7½ in,	6 "
	"	3d.	9 ft. 1½ in.	5½ "
	Second pile	1st.	7 ft. 2 in.	8 "
	"	2d.	7 ft. 10 in.	6 "
	"	3d.	8 ft. 4 in.	7½ "
	Third pile	1st.	7 ft. 6 in.	6⅝ "
	"	2d.	8 ft. ⅝ in.	7¼ "
	"	3d.	8 ft. 8 in.	7½ "
	Fourth pile	1st.	6 ft.	7 "
	"	2d.	6 ft. 7 in.	7 "
	"	3d.	7 ft. 2 in.	9½ "
	Fifth pile	1st.	6 ft. 6 in.	7¼ "
	"	2d.	7 ft. 1¼ in.	7 "
	"	3d.	7 ft. 8¼ in.	8⅛ "
	Sixth pile	1st.	7 ft. 7½ in.	8⅞ "
	"	2d.	8 ft. 4⅝ in.	11½ "
	"	3d.	9 ft. 3½ in.	11⅝ "
	Seventh pile	1st.	8 ft.	18½* "
	"	2d.	9 ft. 6½ in.	9½ "
	"	3d.	10 ft. 4 in.	9½ "

The next step was to determine what amount of friction this clay would afford as a resistance to the sliding outward of the wall on its base, where it has no foothold, standing on a level with the harbor floor.

For this purpose, a rough block of granite was dragged over a level bed of clay, immersed in the water, while the amount of force needed to produce sliding was measured with a spring balance. A mean of some 42 trials gave for the coefficient of friction at starting, 0.328, and after starting, 0.224, while in motion. In practice this can be largely increased by depositing broken stone on the bottom.

The actual condition here existing, affecting the stability of this work, may be described as follows: The wall is, except for a short distance at each end, to act as a retaining wall for the solid filling behind it, while the ebb and flow of the tides bring a mass of water in its front, varying some 12 feet in height—being from 22 to 34 feet in depth at spring tides. Since the lower 12 courses are laid without cement, the water passes freely through the wall, rising and falling with every tide among the material in its rear, as far as such material is not impervious to it. A porous ballast is placed immediately behind the wall, but beyond this the material, for 36 feet in height above its base, is a slippery clay, reduced by handling to a semi-fluid condition when first deposited, and

* Mud.

acquiring gradually a more solid character by the expulsion of water from among its particles, through their greater specific gravity, which was about double that of sea water. This is a slow process; the well-known characteristic of the material being a tendency to resist the percolation of water through its mass; so that many months elapse after its deposit before it becomes as compact as when first found in the harbor. In this latter condition we are obliged to use it as a foundation to build on. It had been found by actual experiment that this material would bear a load of some 5 000 pounds per square foot without flowing out perceptibly from under this load; also that an increase of load above this point was soon accompanied by a tendency to flow, which was apparently continuous for a number of days, when a load of 16 000 pounds per foot was applied. The quantity of clay to be moved by flow from under such a load would increase materially with the settlement of the load, for the first few inches of the displacement, by the accumulation of this displaced material, after which a channel might be established for its escape. A point of equilibrium seemed to be reached in our experiments, where a slight settlement taking place at first, was checked by this increase of resistance until by successive applications of new loads, a load of about 16 000 pounds per foot was reached, when this settlement seemed to become continuous during the experiment. It was, therefore, considered desirable to limit the maximum load to 5 000 pounds per foot, if possible, although a heavier load might not produce much trouble, within the limits of 7 000 or 8 000 pounds per square foot.

The amount and direction of the pressure exerted upon such a wall by the earth behind it, depend upon these two data: (*A*) The specific gravity of the material; (*B*) the natural slope of the material, when a bank of it is left to assume its own slope. This angle is the natural resultant of the friction of the particles as exerted to prevent sliding, and the gravity of the mass. It is, therefore, sometimes called the angle of friction, and its tangent is the coefficient of friction of the material.

Since the investigations of Prony, in the early part of this century, it has been accepted as proved, that the maximum pressure of earth in such cases is exerted, not by the whole prism lying between its natural slope and the back of the wall, for the tendency to slide in that prism is just balanced by friction, and it would not tend to move at all; but this maximum pressure is exerted by the prism contained between the back of the wall and a plane inclined upward from its base, so as to bisect the angle between the vertical and the natural slope. The sliding of this

prism downward would, therefore, throw the centre of pressure in the direction of this limiting plane on which the sliding takes place, *i. e.*, parallel to it; and as the centre of gravity in such a prism, if homogeneous, would be at two-thirds the distance from the top of the wall to the centre of this sloping plane, the line of pressure would strike the back of the wall at a point one-third way up from the base. The value of the horizontal thrust on the wall at this point is expressed by the following formula:

$$P = \frac{Wh^2}{2} \text{ tangent}^2 \tfrac{1}{2} (90^\circ - \varphi)$$

Where P = horizontal pressure on wall for a unit of length.

W = weight of a cubic unit of filling material.

h = height of wall.

φ = angle of repose of filling material, counting from the horizon.

In other words, this pressure for a unit of length of wall equals the product of the weight of the prism for a unit of length by the tangent of one-half the complement of the angle of repose; for the weight of such a prism is—

$$= \frac{W}{2}, h^2 \text{ tangent } \tfrac{1}{2} (90^\circ - \varphi)$$

Of these elements the weight of the filling is easily obtained, and is found by experiment to be about 125 pounds per cubic foot. The height of the wall is 39 feet. It only remains to find the angle of repose of the material. It is upon this point that all the uncertainty arises which enters into such calculations, and renders them often of little value. The natural slope of earth, when not subject to the wash of water, is generally taken at about 33° 18′. But the clay with which we have to deal possesses, when first deposited, almost the fluidity of mortar, and its natural slope is found to be as low as 3°, till time is given for it to expel the water with which it has been mixed. It follows that a wall of enormous height and breadth of base would be required to hold up such a filling for the period of its transition from a semifluid to a comparatively solid state; so that much economy would result by using plenty of time in so disposing this back filling as to increase the angle of repose as far as possible. The first step in this direction is to place in immediate contact with the rear of the wall a quantity of porous material or ballast, which will not only drain the filling in the immediate neighborhood, but serve to increase the angle of the natural slope. Such material was provided for this purpose in the specifications; viz.: porous gravel,

stones, or oyster-shells. The gravel would have a natural slope of some 33° 18′, and the stones or shells, if used, a slope of 40°. But the prism of greatest pressure would not be composed entirely of such ballast. There would be a considerable amount of clay, and this would tend to make the whole mass slide at a flatter slope than the ballast alone would assume. The natural slope of the combination would be somewhere between that of the two substances considered separately. A large number of experiments made upon the friction of this clay, led us to suppose that its angle of repose, when not mixed with water, was more dependent on its cohesion than friction; and a disposition to flow under extreme pressure was generally developed, even when at its hardest state. If we could rely upon the complete expulsion of the water from its mass before completing the loading of the wall, and if we chose to rely on cohesion, we might rely on a natural slope of some 35° perhaps for that of the ballast and clay together. But the difficulty of attaining this result, and the uncertain character of the element of cohesion, indicate that prudence would require the assumed angle to be less than that of common earth alone; say as small as two of base to one of height, or 26° 34′ for the condition of things soon after loading the wall. In order to indicate the direction and value of the resultant pressure on this supposition, the annexed diagram is made. See plate XIII.

In this diagram the section of the wall is shown by the figure *ABD*. The supposed natural slope of the material behind it, when partially consolidated, is shown by the line *BF*, with an angle of 63° 26′ from the vertical. The prism of maximum pressure would then be included between the lines *BA* and *BE*. It would tend to slide down the line *BE*, and, if composed of homogeneous materials, would give a line of pressure parallel to this side, and intersect the wall at one-third its height above its base. But we have here conditions somewhat different from these. The water passes freely through the wall and the ballast, so that the centre of gravity of the prism *A B E* would not be at the centre of gravity of this triangle. Extreme low water is evidently the time when the greatest earth pressure exists. But the material below the water at any time would not count at its full weight, but at a weight depending on its excess of specific gravity over that of sea water. On computing the centre of gravity of the figure upon this basis we find it at the point *C'*. and drawing thence the line *C' H* parallel with *BE*, we find the line of pressure intersects the back of the wall at a point *H*, more than a foot above the lower third of the height of the wall. The weight of such a

prism one foot long, allowing for the buoyancy of the water, is computed at 50,028 pounds, as indicated under the point C, The horizontal pressure on the wall is then found by the formula above quoted.

$$P = w' \text{ tangent } \tfrac{1}{2}\,(90° - \Phi).$$

w' being the weight of the mass, $ABE = 50{,}028$.

Φ being 26° 34′ and $\frac{1}{2}$ (90° − Φ) being 31° 43′ from which we have $P = 30{,}920$ lbs.

We want now to combine this horizontal force with the weight of the wall. This is supposed to act from its centre of gravity, C, with a vertical force of 53,490 pounds ; the portion below low water being diminished in weight by the buoyancy of the water, and the centre of gravity being higher than that of the figure. The resultant is found by computing the diagonal of the force parallelogram to be in a direction shown by the line IJK, making an angle of 30° 02′ with the vertical. and having a value of 61,790 pounds. This would intersect the base at K, distant 3.85 feet from the outer corner of the wall, and would indicate a degree of instability from the following reasons : The angle 30° 02′ is somewhat greater than the angle of friction between stone and stone, as generally accepted, and decidedly greater than that between stone and clay. This might lead to the sliding forward of the wall. Moreover, the pressure on the base is not uniform, but has a maximum at the point D of some 8,500 pounds per square foot, even supposing the horizontal component of this resultant to be cancelled by friction. It had been found by our experiments above referred to, that a pressure of this amount on the clay bed under the wall began to produce symptoms of flow from under the load, hardly consistent with stability.

But we have thus far neglected the items of water pressure and friction between the filling and the back of the wall. Since a very slight rolling motion in the wall might take place about the point B, without producing friction on the line $B\,A$, it was not thought prudent to rely on this ; although Mosely and some other writers suggest such a reliance. But the water pressure certainly does act to some purpose in assisting stability. For although it flows freely through the wall and the ballast, it meets, sooner or later, an impervious material against which it stops and exerts the known pressure, and a part of this may doubtless be reckoned upon to hold back and cancel, *pro tanto*, the earth pressure. A line is drawn on the diagram showing the water-pressure at extreme low water, intersecting the front of the wall and normal to it, at a point one-third the height from the bottom to top of the water, having a value of

14,112 pounds. If the wall were a tight diaphragm, this would produce the resultant *JL*, when combined with the above described forces. In reality, this resultant may be considered to lie between the lines *KJ* and *JL*. The latter has an angle of 73° 10′ with the horizontal; or 16° 50′ with the vertical, which is evidently within the limits of stability.

The result of the above investigation indicates that it is desirable to keep the material behind the wall in such a condition that the angle of repose would always be slightly greater than here shown, which is a condition verging on the extreme limits of stability. This end can generally be attained by giving attention to the manner in which the filling is deposited; viz., to insure its being deposited in successive layers, giving time for the consolidation of each layer by the expulsion of water from among its particles before applying the next one, and giving each successive layer a slope *from* the wall, by keeping the material highest next the wall. These well-known rules in the application of filling behind a retaining wall are particularly important when using a material like this clay, which acts more like a fluid than a granular substance, and is always inclined to flow under pressure, even when consolidated as far as possible, the only condition being that the pressure shall overcome its cohesion, a power of resistance difficult to determine, and which all prudent engineers hesitate to rely upon.

The above investigation also indicates the apparent lack of stability in case the wall were to be founded directly upon the clay, as at first proposed in 1869, for the friction of granite blocks upon the clay is far inferior to that of the same blocks upon the broken stone, while the latter, being imbedded or indented into the clay at the bottom of the trench, get a far better hold than flat stones would do, resting on a flat clay bottom.

The foundation for the 180 feet of heavy wall between the docks was prepared in the year 1876, as above described, by dredging three or four feet below its base, and levelling up with small broken stones from one to four inches diameter, carefully packed and levelled with a straight-edge. During the year 1876, about seven courses of dimension-stone were laid upon this by divers, each course being alternately all headers and all stretchers up to low water. Each stone was gauged by an inspector before being lowered into the water; and when, in the spring of 1877, the work appeared for the first time above water, there was not over an inch variation in its level throughout its whole length. It has since been finished in cement masonry up to grade 16, the dock walls having been

bonded into it as it was laid. The filling has but recently been applied, but, as the pressure of such filling against the wall is more severe immediately after its application than ever likely to be afterward, its present stability is an apparent guarantee for that of the future. A record of its settlement is appended in Table D.

In the tabular statements appended (tables E, F and G), will be found a record of the payments made under the contracts with Messrs. Clapp & Ballou, also a statement of the quantities of each kind of work done, with the nominal prices attached, by which partial payments have been made during the progress of the work, amounting, when finished, to the contract prices per lineal foot of wall, and square foot of filling.

Testing of Cement used in the Heavy Walls above Low Water.

As this cement was often covered by tide water almost immediately after being applied, and always within 10 or 12 hours, until above high water, it was desirable to use an article possessing the quality of setting quickly, as well as of a uniform quality in other respects, such as fineness, &c. Samples were drawn from each barrel. These were mixed with a definite and minimum quantity of water, and moulded for attachment to the testing apparatus. These samples were then immersed in water for 24 hours and afterwards broken by tension in an apparatus made for the purpose, weighing the force applied on a scale beam. Another apparatus was made to test the resistance to crushing, but this test was not found to be so useful in practice as the former. All barrels were rejected which did not yield a tensile strength of sixty pounds per square inch of section after the twenty-four hours in water. A detailed statement of the results of testing large quantities of cement offered is appended hereto (see Tables H and I), showing the gain in strength by lapse of time while immersed in water for various periods up to two years, also comparison of results for various proportions of sand and for salt and for fresh water for making the mortar.

The pointing of the face joints of this wall was originally of good American cement, applied under the contract, but it was found to have been considerably loosened by the frost during the two past winters between high and low water, and arrangements were therefore made in 1877 to replace this pointing with Portland cement, where not perfectly sound. This was applied without sand, and promises to be more durable in this trying position.

Filling Behind the Walls.

The material for filling was the clay dredged from the harbor, with the exception of the ballast behind the walls and for the upper three feet next the surface. This clay was generally so stiff as to require the use of a heavy scoop dredge, and was brought around the walls in scows and dumped about the time of high water, until the filling had accumulated up to about half tide, after which loaded scows could not be floated. The remainder of the clay was dumped in piles in front of the walls and lifted over them with a clam-shell dredge, which swung its arm around over the wall and dropped the clay into small tramway cars, handled by a light locomotive. The tramways extended over the partially filled flats, supported on pile trestles. The car bodies were not on rockers like gravel cars, but had side boards hinged at the top, with bottoms sloping down on each side from the centre, so that when the side boards were raised the clay slipped out on both sides. The repeated handling had reduced the material to the consistency of mortar, so that it spread for several hundred feet on either side of the tram, and avoided the construction of many lines of trestles.* The ridges left alongside the tramway were removed by wheel-barrows into the hollows. This material as thus dumped weighed about 125 lbs. per cubic foot, and as it was of a semi-fluid consistency, capable of exerting an enormous horizontal pressure, great care was needed in depositing it near the walls to avoid crowding them over or pushing them bodily forward. The method generally adopted was to drop this material over the wall directly on to the ballast, until some four or five feet in depth had accumulated, then to move along and wait several weeks for this first deposit to consolidate by expelling the water from its particles before putting on another layer. After the clay had been accumulated by thus dropping it over the wall to a height near the top of the wall, it sloped back for some hundred feet or more over the material previously dumped from scows, and the dumping from the tramways in the interior of the field finished the clay filling.

The gravel for the ballast behind the walls and part of that used for the surface was brought by scows from dredgings around the Great Brewster Spit, near the mouth of the harbor, and was dumped, hoisted over the wall, and distributed in the same manner as the clay. But the

* It was found in practice that lines of trestles some two hundred feet apart would fill the intervening spaces with but little wheeling of material to level up.

larger portion of the surface gravel was brought in from Readville by rail, about nine miles, on the line of the New York & New England Railway.

Dredging Done.

While getting material for filling the area behind the above described walls, the following dredging has been done:

Fort Point Channel has been dredged on a slope longitudinally beginning with 12 feet, reaching a depth of 23 feet at low water, at a point about midway the length of the heavy wall west of the dock. The portion of this channel opposite the light wall is 400 feet wide. Passing eastward the width gradually contracts to about 200 feet before arriving at the first dock. Near the entrance to this dock, it is widened again to a width of 400 feet, with a depth of 23 feet at low water. This width allows vessels to turn in entering or leaving the dock. From this point, a channel is dredged about 200 feet wide and 23 feet deep at low water nearly due east to the main ship channel. A considerable amount of material has also been taken from a shoal off the end of Long Wharf.

The dock on the Commonwealth's flats has a depth of 23 feet at low water through its whole length, up to within 50 feet of the walls on each side, which is as near the walls as it will be safe to dredge, before the platforms are built, owing to the difficulty in controlling the dredging machines with any exactness. This bank of clay on each side will be a sufficient protection to the walls until the platforms are built, after which it may or may not be found necessary to dredge a small quantity along their front lines.

Inspection.

The difficulty of inspecting submarine masonry is often felt to be a serious drawback upon its use. The difficulty in most cases arises in part from the lack of intelligence and habits of accurate observation on the part of the men employed as divers, and in part from the possible want of independent judgment, veracity, and integrity in men who either have been, are now, or expect to be in the future, dependent for employment upon the contractors whose work they are to examine and report upon. Perfect independence is a *sine qua non* for a good inspector, however good his other qualifications may be. In the work above described the State was fortunate in securing the services of the assistant engineer in charge to inspect all the submarine work in person. This was done in ordinary diver's armor, and without any injurious effects except temporary discomfort at times.

TABLE A.

LEVELS ON THE FORT POINT CHANNEL AND DOCK WALLS.—SHOWING SETTLEMENT.

(Referred to Mean Low Water.)

FORT POINT CHANNEL WALL. Distances from commencement of curve of 910 feet radius.	ELEVATION. 1874.	ELEVATION. 1877. December 8.	DOCK WALL. Lettered stations are about 50 feet apart.	ELEVATION. 1876.	ELEVATION. 1877. December 8 and 10.	DOCK WALL. Lettered stations are about 50 feet apart.	ELEVATION. 1876.	ELEVATION. 1877. December 10.
END OF WALL.			WEST SIDE.			EAST SIDE.		
314½ feet S. of P. C.	16.00	15.62	Y,	16.00	15.89	S. E. corner, I − 7	16.00	15.91
300 " "	16.00	15.79	X + 25	16.00	15.86	I,	16.00	15.90
275 " "	16 00	15.73	X,	16.00	15.84	+ 25	16.00	15.92
250 " "	16.00	15.65	W + 25	16.00	15.91	J,	16.00	15.87
225 " "	16.00	15.70	W,	16.00	15.87	+ 25	16.00	15 80
200 " "	16.00	15.56	V + 25	16.00	15.96	K,	16.00	15.86
175 " "	16.00	15.48	V	16.00	15.94	+ 25	16.00	15.74
150 " "	16.00	15.66	U + 25	16.00	15.81	L,	16.00	15.92
125 " "	16.00	15.66	U,	16.00	15.69	+ 25	16.00	15.87
100 " "	16.00	15.73	T + 25	16.00	15.74	M,	16.00	15.85
75 " "	16.00	15.78	T,	16.00	15.77	+ 25	16 00	15.83
50 " "	16.00	15.93	S + 25	16.00	15 84	N,	16.00	15.88
25 " "	16.00	16.06	S,	16.00	15.83	+ 25	16.00	15.96
0 " "	16.00	15.94	R + 25	16.00	15.83	O,	16.00	15.86
25 " N. of P. C.	16.00	15.66	R,	16.00	15.93	+ 25	16.00	15.90
50 " "	16.00	15.82	Q + 25	16.00	15.77	P,	16.00	15.85
75 " "	16 00	15.86	Q,	16.00	15.83	+ 25	16.00	15.92
100 " "	16.00	15.99	P + 25	16.00	15.79	Q,	16.00	15.88
125 " "	16.00	15.98	P,	16.00	15.76	+ 25	16.00	16.00
150 " "	16.00	16.09	O + 25	16.00	15.70	R,	16.00	15.98
175 " "	16.00	16.02	O,	16.00	15.74	+ 25	16.00	15.94

200 feet N. of P. C.	16.00	15.81
225 " "	16.00	15.94
250 " "	16.00	15.91
275 " "	16.00	15.90
300 " "	16.00	15.71
325 " "	16.00	15.71
350 " "	16.00	15.80
375 " "	16.00	15.80
Corner	16.00	15.84
Middle of Spur to Heavy Wall	16.00	15.88
	16.00	15.81
	15.81	
Average settlement, =	0.19	

N + 25	16.00	15.76
N,	16.00	15.80
M + 25	16.00	15.86
M,	16.00	15.70
L + 25	16.00	15.83
L,	16.00	15.81
K + 25	16.00	15.79
K,	16.00	15.69
J + 25	16.00	15.78
J,	16.00	15.83
I + 25	16.00	15.76
I,	16.00	15.71
S.W.cor. I — 7	16.00	15.63
	16.00	15.80
	15.80	
Average settlement, =	0.20	

END.

25 feet from S.W. corner	16.00	15 62
50 " "	16.00	15.95
75 " "	16.00	15.81
100 " "	16.00	15.84
125 " "	16.00	15.81
150 " "	16.00	15.88
	16.00	15.82
	15.82	
Average settlement	0.18	

S,	16.00	15.92
+ 25	16.00	15.94
T,	16.00	15.91
+ 25	16.00	15.82
U,	16.00	15.69
+ 25	16.00	15.86
V,	16.00	15.89
+ 25	16.00	15.94
W,	16.00	15.79
+ 25	16.00	15.95
X,	16.00	15.84
+ 25	16.00	16.00
Y,	16.00	15.79
+ 25	16.00	15.92
Corner, junction with heavy wall	16 00	16.06
	16.00	15.89
	15.89	
Average settlement, =	0.11	
Mean of levels on the whole dock		15.84
	16.00	
	15.84	
Average settlement on whole dock	0.16	

TABLE B.

LEVELS ON HEAVY WALL, WEST OF DOCK. SHOWING AMOUNT OF SETTLEMENT. THE ORIGINAL LEVEL OF COPING WAS 16.00.

[Referred to Mean Low Water.]

Lettered stations are 17.61 feet apart; Dolphins, 105.64 feet apart.		ELEVATION OF TOP OF BOTTOM COURSE.										Height of Wall above Bottom Course. (Bottom C = 2 feet.)	Elevation of Top of Wall (front line of caps) Dec. 8, 1877.
		Oct. 7, to Nov. 16, 1874.	Nov. 28, to Dec. 2, 1874.	April 1 and 2, 1875.	May 6, 1875.	May 21, 1875.	July 8 and 9, 1875.	Aug. 27, 1875.	Oct. 12, 1876.	Oct. 15, 1877.	Dec. 8, 1877.		
West end of wall	A	— 9.24	..	— 9.24	..	..	..	..	— 9.87	— 9.91	— 9.94	25.57	15.63
Dolphin No. 4, 29 feet from west end of caps	B	— 8.98	— 8.98	— 8.99	..	..	— 9.18	..	— 9.76	— 9.80	— 9.81	25.41	15.60
	C	— 9.03	— 9.02	— 9.06	..	..	— 9.18	..	— 9 87	— 9 92	— 9.96	25.53	15.57
	D	— 9.11	— 9.12	— 9.11	..	.	— 9.20	..	— 9.89	— 9.93	— 9.96	25.47	15.51
	E	— 9.13	— 9.13	— 9.14	..	..	— 9.25	..	—10.06	—10.09	—10.11	25.58	15.47
	F	— 9.11	— 9.12	— 9.11	..	..	— 9.27	..	—10.10	—10.15	—10.18	25.58	15.40
	G	— 9.03	— 9.03	— 9.03	..	..	— 9.16	..	—10.00	—10.03	—10.06	25.46	15.40
	H	— 8.97	— 8.97	— 8.99	..	..	— 9.08	..	— 9.88	— 9.90	— 9.93	25.40	15.47
Dolphin No. 5	I	— 8.81	— 8.82	— 8.84	..	..	— 8.94	..	— 9.73	— 9.75	— 9.77	25.27	15.50
	J	— 9.03	— 9.03	— 9.05	..	..	— 9.12	..	— 9.89	— 9.92	— 9.95	25.45	15.50
	K	— 8.95	— 8.94	— 8.95	..	..	— 9.06	..	— 9.82	— 9.85	— 9.89	25.35	15.46
	L	— 8.96	— 8.97	— 8.98	..	..	— 9.08	..	— 9.79	— 9.82	— 9.87	25.38	15.51
	M	— 8.92	— 8.92	— 8.92	.	..	— 9.10	..	— 9.73	— 9.78	— 9.85	25.31	15.46
	N	— 9.02	— 9.03	— 9.02	..	..	— 9.16	..	— 9.81	— 9.88	— 9.95	25.38	15.43
Dolphin No. 6	O	— 9.03	— 9.05	— 9.03	..	..	— 9.12	..	— 9.81	— 9.84	— 9.90	25.36	15.46
	P	— 8.95	— 8.99	— 8.97	..	..	— 9.10	..	— 9.75	— 9.78	— 9.84	25.35	15.51
	Q	— 8.96	— 9.00	— 8.98	..	.	— 9.08	..	— 9.70	— 9.73	— 9.77	25.29	15.52
	R	— 9.03	— 9.04	— 9.05	..	..	— 9.11	..	— 9.74	— 9.76	— 9.80	25.33	15 53
	S	— 8.97	— 8.98	— 9.00	..	..	— 9.09	..	— 9.73	— 9.75	— 9.77	25.36	15.59
	T	— 8.93	— 8.94	— 8.96	..	..	— 9.10	..	— 9.80	— 9.81	— 9.84	25.39	15.55

Dolphin No. 7....	U.....	— 8.90	— 8.91	— 8.94	— 8.94	..	— 9.06	— 9.05	— 9.76	— 9.78	— 9 80	25.38	15.58
	V.....	..	— 8.97	— 9.00	— 9.00	..	— 9.08	— 9.10	— 9.74	— 9.76	— 9.79	25.39	15.60
	W.....	..	— 9.02	— 9.06	— 9.09	..	— 9 14	— 9.17	— 9.84	— 9.88	— 9.90	25.51	15.61
	X.....	..	— 8.91	— 8.95	— 8.95	..	..	— 9.07	— 9.69	— 9.73	— 9.74	25.36	15.62
	Y.....	..	— 8.88	— 8.93	— 8.93	..	..	— 9.05	— 9 69	— 9.73	— 9.76	25.42	15.66
	Z.....	..	..	— 9.02	— 9.02	— 8.92	..	— 9.13	— 9.63	— 9.65	— 9.68	25.32	15.64
Dolphin No. 8....	A'.....	..	— 8.93	— 8.97	— 8.97	— 9.04	..	— 9.05	— 9.65	— 9 67	— 9.70	25.41	15.71
	B'.....	..	..	..	..	— 8.98	..	— 9.04	— 9.61	— 9.64	— 9.66	25.44	15.78
	C'.....	..	..	..	..	— 8.99	..	— 9.02	— 9 53	— 9.57	— 9 59	25.32	15.73
	D'.....	..	..	..	..	— 8.98	..	— 9.22	— 9.52	— 9.57	— 9.60	25.33	15.73
	E'.....	..	..	..	..	— 9.18	..	— 8.94	— 9.40	— 9.46	— 9.49	25.27	15.78
	F'.....	..	..	..	..	— 8.94	..	— 8.95	— 9.45	— 9.56	— 9.60	25 36	15.76
Dolphin No. 9....	G'.....	..	..	..	..	— 8.98	..	— 9.03	— 9 48	— 9.55	— 9.58	25.36	15.78
	H'.....	..	..	..	..	— 9.03	..	— 9.07	— 9·48	— 9.57	— 9.59	25.36	15.77
	I'.....	..	..	..	..	— 9.06	..	— 9.15	— 9.41	— 9.51	— 9.55	25.32	15.77
	J'.....	..	..	..	..	— 9.12	..	— 9.16	— 9.60	— 9.70	— 9.74	25.46	15.72
	K'.....	..	..	..	..	— 9.06	— 9.10	— 9.10	— 9.57	— 9.70	— 9.74	25.39	15.65
	L'.....	..	..	..	..	— 9.04	— 9.10	— 9 09	— 9.54	— 9.68	— 9.72	25.36	15.64
Dolphin No. 10....	M'.....	..	..	..	..	— 9.07	— 9.12	— 9.12	— 9.52	— 9.69	— 9.74	25.39	15.65
	N'.....	..	..	..	..	— 9.04	— 9.09	— 9.06	— 9.49	— 9.66	— 9.70	25.35	15.65
	O'.....	..	..	..	..	— 9.08	— 9.10	— 9.10	— 9.54	— 9.71	— 9.75	25.48	15.73
	P'.....	..	..	..	..	..	— 9.08	— 9.04	— 9.43	— 9.59	— 9.62	25.36	15 74
	Q'.....	..	..	..	..	..	— 9.14	— 9.10	— 9.45	— 9.61	— 9.64	25.39	15.75
	R'.....	..	..	..	..	..	— 9.14	— 9.17	— 9.50	— 9.64	— 9.68	25.43	15.75
Dolphin No. 11....	S'.....	..	..	..	..	..	— 9.05	— 9.05	— 9.47	— 9.58	— 9.61	25.38	15.77
	T'.....	..	..	..	..	..	— 9.05	— 9.15	— 9.46	— 9.54	— 9.55	25.36	15.81
East end of wall	U'.....	..	..	..	..	..	— 9.08	— 9.20	— 9.49	— 9.54	— 9.57	25.42	15.85
Mean of first levels.....							— 9.02	Mean of last levels...			— 9.77	25.39	15.62
											9.02		
								Average settlement...			0.75		
								Greatest settlement...			1.07		
								Least settlement.....			0.49		

TABLE C.

HEAVY WALL WEST OF DOCK.—APPROXIMATE PROGRESS OF MASONRY BY DOLPHIN RANGES.

NUMBER OF COURSE.	West End Begun.	No. 4.	No. 5.	No. 6.	No. 7.	No. 8.	No. 9.	No. 10.	East End No. 11. +
1	1874. Aug. 25,	1874. Sept. 1.	1874. Sept. 5,	1874. Oct. 22,	1874. Nov. 7,	1874. Dec. 1,	1874. Dec. 5,	1874. Dec. 29.	1875. June 24,
2	Sept. 5,	Sept. 10,	Oct. 1,	Nov. 2,	Nov. 17,	Dec. 30,	1875. Jan. 9,	1875. April 19,	June 30.
3	1875. April 12,	1875. April 13,	1875. April 22,	1875. May 1,	1875. May 28,	1875. July 9,	Aug 7,	Aug 13,	Sept. 28,
4	May 5,	May 5,	May 15,	May 26,	June 9,	July 20,	Sept. 2,	Oct. 4,	Oct. 13,
5	June 1,	June 2,	June 18,	July 10,	July 22,	Aug. 18.	Sept. 17,	Oct. 9,	Nov. 5,
6	June 11.	June 14,	June 28,	July 25,	July 28,	Aug. 31,	Sept. 23,	Oct. 15,	Nov. 15.
7	July 3,	July 15,	July 30,	Aug. 15,	Aug. 30,	Sept. 25,	Oct. 5,	Nov. 10,	..
8	July 10,	July 20,	Aug. 15,	Aug. 30,	Sept. 10,	Sept. 30,	Oct. 10,	Nov. 15,	..
9	July 13,	July 23,	Aug. 20,	Sept. 15,	Sept. 25,	Oct. 2,	Oct. 12,	Nov. 20,	..
10	..	July 25,	Aug. 25,	Sept. 19,	Sept. 28,	Oct. 10,	Oct. 25,	1876.	1876.
11	July 29,	Aug. 3,	Aug. 30,	Sept. 22,	Sept. 30,	Oct. 15,	Oct. 28,	1876.	1876.
12	Aug. 10,	Aug. 31,	Sept. 5,	Sept. 25,	Oct. 1,	Oct. 16,	Oct. 29,	1876.	1876.
13	Nov. 11,	..	..	..	..	..	..	1876.	Sept. 7.

TABLE D.

LEVELS ON HEAVY WALL EAST OF DOCK.—(Referred to Mean Low Water.)

Regular Stations are 20.42 feet apart.		Elevation of Bottom Course.		Height of Wall above Bottom Course (Bottom C. = 2 feet).	Elevation of Top of Wall (Front line of Caps), Dec. 20, 1877
		Sept. 26, 1877.	Dec. 20, 1877.		
End of wall	A,	—20.94	—20.94	37.01	16.07
	B,	—21.04	—21.09	37.11	16.02
	C,	—21.04	—21.07	37.12	16.05
	D,	—21.00	—21.04	37.06	16.02
Dolphin, No. 14, 73.6 ft. from W. end of caps	E,	—20.96	—20.99	37.05	16.06
	F,	—21.00	—21.03	37.11	16.08
	G,	—21.00	—21.02	37 10	16.08
	H,	—21.03	—21.06	37.17	16.11
	I,	—20.95	—20.98	37.10	16.12
Dolphin, No. 15, 105.1 ft. from E. end of caps	J,	—20.94	—20.96	37.13	16.17
End of wall	K,	—20.93	—20.95	37.09	16.14
Mean of latest levels		.....	—21.01	37.09	16.08
Original elevation, top of bottom course		.....	—20.08		
Average settlement		.....	—0.21		
Greatest settlement		.....	—0.29		
Least settlement		.....	—0.14		

N. B.—The datum used for these levels is the same hitherto used in connection with the office of Harbor Commission and Coast Survey. It varies slightly from the datum of the City Engineer's office. This datum can be found by the following bench marks, viz.: North-east corner of door-step of office of Boston Water Board's pipe-yard on Federal street, opposite New York and New England Railroad Station, is called 19.839; coping of Dry Dock in Navy Yard, 14.620.

TABLE E.

RECORD OF PAYMENTS MADE UNDER THE CONTRACTS WITH MESSRS. CLAPP & BALLOU.

WORK DONE.	Lineal Feet.		Square feet of Filling.	Total value at the Contract prices.	Reserved under Contract.	Actually Paid.
	Light Wall.	Heavy Wall.				
Before Jan. 1, 1875	641	255.	190,016	$160,139 00	$16,013 88	$144,125 12
Jan. 1, 1876	1,138	743.	349,216	357,682 26	35,768 20	321,914 06
Jan. 1, 1877	2,415	879.	561,692	525,228 21	52,522 82	472,705 39
Jan. 15, 1878	2,635	944.849	884,010 $\frac{6}{10}$	676,313 68	67,631 29	608,682 39

TABLE F.

THE QUANTITIES OF WORK ACTUALLY DONE AT THE VARIOUS POINTS ARE ABOUT AS FOLLOWS, VIZ.;

LOCALITY.	Length on Top.	Tons.	Cubic Yards.
Fort Point Channel wall	$720\frac{49}{100}$	....	$3,187\frac{951}{1000}$
" " broken stone at north end	....	743.	....
Heavy wall west of docks	$802\frac{783}{1000}$	....	....
" " masonry laid by divers	....	....	$3.794\frac{675}{1000}$
" " masonry in cement	....	....	$2,639\frac{437}{1000}$
" " foundations of broken stones.	...	20,500 or	$12,904\frac{827}{1000}$
Heavy wall east of dock	$132\frac{53}{100}$ *	....	....
" " masonry by divers	....	....	$1,638\frac{871}{1000}$
" " masonry in cement	....	....	$606\frac{157}{1000}$
" " broken stone in foundation	....	923	....
Dock wall	1861	....	...
" " masonry	....	....	$8,241\frac{576}{1000}$
" " broken stone at north-west corner	....	737	....
" " broken stone at north-east corner	....	1,105	....
" " broken stone under west wall	....	146	....

TABLE G.

Partial payments have been made according to the following list of nominal prices furnished by the contractor, amounting, when multiplied by the estimated quantities of each kind of work, to the contract price per lineal foot of walls: viz.:—

FOR WALL ALONG FORT POINT CHANNEL AND AROUND DOCK:

For piles and planking same, 2 piles per lineal foot, at $5 each	$10 00	per foot.
Digging out and applying ballast between piles	1 50	"
Masonry, $4\frac{1}{2}$ yards per foot, at $3.32 + per yard	15 50	"
Ballasting back of wall, $7\frac{1}{2}$ yards per foot, at $1.50	11 00	"
Guide piles	1 00	"
Total	$39 00	per foot.

FOR HEAVY SEA-WALL WEST OF DOCK.

Broken stone in foundation	$3 00	per yard.	
Levelling the same	50	"	
Guide piles for same	05	"	
15.5 cubic yards per foot length	$3 55	"	$55 025 per foot.
Masonry below low water, 4,691 yards, @ $18			84 438 "
Masonry above low water, 4,531 yards, @ $17.775			80 537 "
Ballast behind wall			16 000 "
Total, as per contract price			$236 000 "

FOR HEAVY WALL BETWEEN THE DOCKS.

Masonry laid by divers, 11.95 yards, @ $15	$179 25	per foot.
Masonry laid above water, 4.531 yards @ $10	45 75	"
Levelling foundation	5 00	"
Ballast behind wall	18 50	"
Total	$248 50	"

* On State's land.

Table H.

Record of Cement Tests.

All from moulds of neat cement mixed with fresh water and broken by tension after immersion for time stated. Temperature of water used in mixing about 60° Fahr't.

Age.	Newark & Rosendale Cement Co. 24-hour tests are from 891 barrels.		Newark, N. J., Lime and Cement Co. 24-hour tests are from 440 barrels.		Newark. N. J., Lime & Cement Co. All tests from 1 barrel.		New York & Rosendale Lime & Cement Co. 24-hour tests are from 180 barrels.		Lawrence Cement Co. "Hoffman Rosendale Cement." Tests from 5 barrels.		Howe's Cave Association. Tests from 4 barrels.	
	No. of tests.	Average strength in lbs. per square inch.	No. of tests.	Average strength in lbs. per square inch.	No. of tests.	Average strength in lbs. per square inch.	No. of tests.	Average strength in lbs. per square inch.	No. of tests.	Average strength in lbs. per square inch.	No. of tests.	Average strength in lbs. per square inch.
16 hours.	54	47	....	....	....	....	....	....	....	....	....	....
24 "	2 217	54.7	1 204	63.1	10	58.	467	45.	6	44.	14	60.
36 "	267	55.3	....	....	....	....	....	....	....	....	....	....
48 "	51	59.6	9	64.	....	....	3	78.5	14	49.5	11	49.
60 "	35	67.6	....	....	....	....	....	....	....	....	....	....
72 "	...	....	....	....	....	....	....	....	....	....	3	77.
4 days.	....	....	....	....	....	....	....	....		72.5	....	....
7 "	28	97.1	....	....	24	71.	1	85.	....	....	....	....
10 "	....	....	....	....	....	....	2	97.5	2	105.	....	....
14 "	12	120.4	....	....	....	....	....	....	....	....	....	....
15 "	....	....	2	133.7	....	....	3	88.	....	....	....	....
19 "	8	139.8	....	.	....	....	....	....	....	....	....	....
21 "	....	....	....	....	....	....	....	....	2	97.	....	....
25 "	....	....	....	....	....	....	....	....	....	....	1	117.
1 month.	....	....	....	....	21	91.8	....	...	7	107.5	....	....
64 days.	....	....	....	....	...	....	1	297.	....	....	....	....
69 "	....	....	....	....	....	....	1	325.	....	....	....	....
2 months.	....	....	....	....	25	157.2	....	....	8	201.5	....	....
3 "	....	....	....	....	....	....	....	....	....	....	1	175.
3¼ "	....	....	....	....	....	....	....	....	2	220.5	....	....
4 "	....	....	....	....	....	....	....	....	....	....	1	177.
6 "	....	....	....	....	....	....	....	....	2	250.	....	....
1 year.	....	....	....	....	....	....	....	....	9	380.6	....	....
1¼ years.	....	....	....	....	29	241.4	....	....	....	....	....	....
2 "	26	257.1	....	....	33	385.1	19	335.5	13	265.8	11	291.7

Table I.

Record of Cement Tests.

From moulds of neat cement mixed with salt water and broken by tension after immersion for time stated.

Temperature of water used in mixing about 60° Fahr't.

Neat Cement.

Age.	Newark, N. J., Lime & Cement Co.		Lawrence Cement Co. "Hoffman Rosendale."	
	No. of tests.	Average strength in lbs. per square inch.	No. of tests.	Average strength in lbs. per square inch.
24 hours.	22	38.9	2	18.7
2 days.	..	....	13	45.
4 "	..	....	2	40.5
7 "	15	56.3	..	....
10 "	..	...	2	49.5
20 "	..	....	3	63.
1 month.	31	105.	3	79.
2 months.	..	....	4	134.
3¼ "	..	....	1	275.
6 "	..	....	4	237.
1 year.	..	....	3	366.7
1¼ years.	29	205.3	..	....
2 "	33	311.	14	233.6

Records of Pile Driving.

The notes on the following pages are from personal observation and measurement, and, together, give a fair statement of the quality of the foundation reached between the Boston Wharf Company's property and the southerly extremity of the heavy wall.

The material is (1) mud, varying in depth from 1 foot to 3 or 4 feet; (2) sand, mud, and clay, in all proportions and so differently mixed that but little can be definitely stated about their arrangement. Frequently muddy sand occurs for 10 feet or more, and is then succeeded by a sandy

yellow clay or by thin seams of quite pure clay alternating with thin seams of sand. Again the mud, sand, and clay, are so intimately mixed that the piles show no difference in penetration other than what is due to the change of fall, &c.

Memorandum of Pile Driving for Foundation of the Light Sea Wall in the State Dock.

Whole number of spruce piles driven in State dock wall foundation under contract of June 23, 1875, 3,645. These by specifications to be 10 inches or more in diameter where sawed off at top.

Books record distances driven for 3,089 of these, aggregating 65,627.5 feet, or an average penetration of 21.25 feet. The least penetration recorded is 14.5 feet. The greatest penetration recorded is 28 feet.

As the trench in which these piles were driven averaged more than 4 feet deep at mean low water, and the penetration when piles were dropped before driving is not included in the above figures, at least 5 feet should be added to the above penetrations to show depths which piles reached below mean low water :

TABLE J.

State Dock.	Depth driven in feet.	Fall of Hammer in feet.	Penetration in inches, last blow.	Number of piles.
Average	21.285	26.444	3.768	1861
Piles with max. penetration.	21.	27.	12.	1
Piles with min. penetration.	17 to 22½, av. 19.2	10 to 28, av. 23.9	1.	9
B. & A. Dock, spur.				
Average	22.054	23.839	5.714	56
Piles with max. penetration.	20.	20.	12.	1
Piles with min. penetration.	22 to 24, av. 23.33	24 to 27, av. 25.33	3.	3

State Dock.	Depth driven in feet	Number of blows.	Penetration in inches, last blow.	Number of piles.
Average	20.988	33.482		83
Piles requiring greatest number of blows	21.	59.	2 inches, with 27 ft. fall.	1
Piles requiring least number of blows	16.	12.	4 inches, with 27 ft. fall.	1

Weight of hammer used, 1,400 pounds.

MEMORANDUM OF PILE DRIVING FOR FOUNDATION OF LIGHT SEA WALL ALONG EAST SIDE OF FORT POINT CHANNEL.

Date.	Whole depth to which piles were driven by hammer.	Last blow.		Hammer used weighed 1,400 pounds.
		Fall in feet.	Penetration in inches.	
Nov. 10th, 1873.	25 feet.	25 feet.	8 inches.	Penetration 6 inches by 18th blow, penetration 2¼ inches by 6th blow.
Dec. 24th.	25 ft. or more.	25 "	12 "	Piles 35 feet to 41 feet long.
" 29th.	25 ft. to 30 ft.	25 "	12 " +	Penetration 8 inches with 20 to 25 ft. fall when 20 ft. in ground.
Jan., 1874.	20 ft. to 25 ft.	30 "	6 " +	
"	20 ft. to 25 ft.	30 "	4 in. to 8 in.	
"	18 ft. to 25 ft.	30 "	3 in. to 6 in.	
"	20 feet.	30 "	4 in. to 8 in.	Clay at 15 feet.
"	25 ft. or more	30 ft. to 33 ft.	11 inches.	
"	18 ft. to 30 ft.	30 feet.	6 inches.	These finding clay at 15 feet down.
"	25 ft. to 30 ft.	30 ft. to 33 ft.	8 in. to 14 in.	These finding no stiff material.
"	25 feet.	30 ft. to 35 ft.	6 in. to 12 in.	Driven 8 ft. or more in clay, and moving much less per blow when 3 ft. or 4 ft. in clay than at last blow.
"	25 feet.	30 ft. to 35 ft.	3 in. to 10 in.	
"	25 feet.	30 ft. to 35 ft.	8 in. to 14 in.	Driven 8 ft. to 10 ft. in clay.

Piles used were of spruce, and about 10 inches diameter at surface of ground.

On three occasions piles driven 20 feet or more in the ground, with penetration of about 12 inches by last blow with 25 feet fall, were again struck after 12 or more hours with the same fall, the consequent penetration being only 3 to 4 inches.